Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-CISD–2011/016 December 2011
Center for Innovation in Ship Design
Technical Report

TriSWACH ASW Corvette

By
Keisuke Suzuki

NSWCCD-CISD-2011/016 TriSWACH ASW Corvette

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 01-12-2011	**2. REPORT TYPE** Final	**3. DATES COVERED** *(From - To)* Apr 2011 – Dec 2011
4. TITLE AND SUBTITLE TriSWACH ASW Corvette		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Keisuke Suzuki		**5d. PROJECT NUMBER**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES) Naval Surface Warfare Center Carderock Division 9500 MacArthur Boulevard West Bethesda, MD 20817-5700		**8. PERFORMING ORGANIZATION REPORT NUMBER** NSWCCD-CISD-2011/016
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Chief of Naval Research One Liberty Center 875 North Randolph Street, Suite 1425 Arlington, VA 22203-1995		**10. SPONSOR/MONITOR'S ACRONYM(S)** ONR
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release: Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The objective of this project is to develop a concept design of a Trimaran Small Waterplane Area Centerhull (TriSWACH) Anti Submarine Warfare (ASW) corvette. The advantages of using the TriSWACHs are the hullform's inherent good seakeeping at small displacement, good intact stability, large usable deck area compared to monohulls, and small installed power compared to Small Waterplane Area Twin Hulls (SWATHs). The design is an 1,845 mt vessel, with a length of 102 m and an overall beam of 24.3 m. The vessel has been designed for a manning of 59 personnel. The propulsion system is diesel electric with installed power of 12,400 kW. The maximum speed is 25 knots and the range is 3,500 nm at 15 knots. The vessel has ASW armaments (torpedo tube, Vertical Launch Anti-Submarine Rocket, hull mounted sonar and Towed Array Sonar). In addition, to enhance the ASW capability, a helo flight deck is added. In the case of trimarans, there are many parameters that influence the hullform. As references, three cases were examined: the impact of (1) slenderness of centerhull alone on effective power, (2) sidehull configurations on effective power and (3) sidehull configurations on intact stability. The damaged stability is also confirmed. The most severe case is when one sidehull is damaged and both the other sidehull and the centerhull are intact. To improve this situation, the insides of the sidehulls are assumed to be foam filled spaces. To confirm the effect of using lightweight materials for the hull structures, the case of titanium hull structures is analyzed. By using titanium, there is the possibility to save 314 mt of the full load displacement.

15. SUBJECT TERMS
TriSWACH, Trimaran, Corvette, ASW

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Colen Kennell
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	SAR	25	**19b. TELEPHONE NUMBER** *(include area code)* 301-227-5468

Abstract

The objective of this project is to develop a concept design of a Trimaran Small Waterplane Area Centerhull (TriSWACH) Anti Submarine Warfare (ASW) corvette. The advantages of using the TriSWACHs are the hullform's inherent good seakeeping at small displacement, good intact stability, large usable deck area compared to monohulls, and small installed power compared to Small Waterplane Area Twin Hulls (SWATHs).

The design is an 1,845 mt vessel, with a length of 102 m and an overall beam of 24.3 m. The vessel has been designed for a manning of 59 personnel. The propulsion system is diesel electric with installed power of 12,400 kW. The maximum speed is 25 knots and the range is 3,500 nm at 15 knots. The vessel has ASW armaments (torpedo tube, Vertical Launch Anti-Submarine Rocket, hull mounted sonar and Towed Array Sonar). In addition, to enhance the ASW capability, a helo flight deck is added.

In the case of trimarans, there are many parameters that influence the hullform. As references, three cases were examined: the impact of (1) slenderness of centerhull alone on effective power, (2) sidehull configurations on effective power and (3) sidehull configurations on intact stability.

The damaged stability is also confirmed. The most severe case is when one sidehull is damaged and both the other sidehull and the centerhull are intact. To improve this situation, the insides of the sidehulls are assumed to be foam filled spaces.

To confirm the effect of using lightweight materials for the hull structures, the case of titanium hull structures is analyzed. By using titanium, there is the possibility to save 314 mt of the full load displacement.

Acknowledgement

I would like to express my appreciation to Dr. Colen Kennell, Mr. Andrew Tate, Mr. David Widhalm and George Lamb for their advice and support of this project.

Contents

List of Figures

List of Tables

Acronyms

ACCeSS	Atlantic Center for the Innovative Design & Control of Small Ships
A_{FRONT}	Frontal Area of HAMA Strip
A_{MAX}	Maximum Cross-Sectional Area
AP	Aft Perpendicular
ASW	Anti-Submarine Warfare
ASuW	Anti-Surface Warfare
A_W	Waterplane Area
A(X)	Cross-Sectional Area at longitudinal position “X”
BM	Transverse Metacentric Radius
B_{MAX}	Maximum Beam
B.L.	Baseline
B_{WL}	Beam at Design Waterline
C_A	Correlation Allowance Coefficient
CAD	Computer Aided Design
CAPTAS	Combined Active and Passive Towed Array Sonar
C_F	$= R_F /(0.5\rho V^2 S)$, Frictional Resistance Coefficient
CFD	Computational Fluid Dynamics
C_{HAMA}	$= R_{HAMA} /(0.5\rho V^2 A_{FRONT})$ =1.25, Hama Strip Resistance Coefficient [7]
CISD	Center for Innovation in Ship Design
CODOG	Combined Diesel or Gas Turbine
C_R	$= R_R /(0.5\rho V^2 S)$, Residuary Resistance Coefficient
CRP	Contra-Rotating Propeller
C_T	$= R_T /(0.5\rho V^2 S)$, Total Resistance Coefficient
C_W	$= R_W /(0.5\rho V^2 S)$, Wavemaking Resistance Coefficient
DDS	Design Data Sheet
D.W.L.	Design Waterline
FCS	Fire Control System
F_N	$= V /(gL_{WL})$, Froude Number
FP	Fore Perpendicular
g	Gravity Acceleration
GM	= KM - KG
KB	Height of Center of Buoyancy above Baseline
KG	Height of Center of Gravity above Baseline
KM	= KB + BM
L_{WL}	Length at Design Waterline
M_{cm}	Moment to change Trim one cm
MCR	Maximum Continuous Rating

mt	Metric Ton
NAVSEA	Naval Sea Systems Command
nm	Nautical Mile
NSWCCD	Naval Surface Warfare Center, Carderock Division
ONR	Office of Naval Research
PC	Propulsive Coefficient
P_E	Effective Power
P_S	Shaft Power
RAM	Rolling Airframe Missile
R_F	Frictional Resistance
R_{HAMA}	HAMA Strip Resistance
RHIB	Rigid Hull Inflatable Boat
R_R	Residuary Resistance
R_T	Total Resistance
R_W	Wavemaking Resistance
S	Wetted Surface Area
SAM	Surface to Air Missile
SFC	Specific Fuel Consumption
SSCS	Ship Space Classification System
SSM	Surface to Surface Missile
SUM	Surface to Underwater Missile
SWATH	Small Waterplane Area Twin Hull
SWBS	Ship Work Breakdown Structure
TAS	Towed Array Sonar
TriSWACH	Trimaran Small Waterplane Area CenterHull
T_{WL}	Draft at Design Waterline
UAV	Unmanned Aerial Vehicle
V	Velocity
VLA	Vertical Launch Anti-Submarine Rocket
VLS	Vertical Launching System
ρ	Liquid Density

1 Introduction

1.1 Objective

The objective of this project is to develop a concept design of a Trimaran Small Waterplane Area Center Hull (TriSWACH) Anti-Submarine Warfare (ASW) corvette. The primary mission of the corvette is littoral ASW. The secondary missions are littoral Anti-Surface Warfare (ASuW); air self defense; intelligence, surveillance, reconnaissance; maritime interdiction operations; homeland defense; and anti-terrorism force protection.

1.2 Background

After the end of the Cold War, small combatants, like corvettes, are becoming an attractive option because (1) many recent operations of navies are in offshore waters and large combatants, like frigates or destroyers, are not suited for littoral warfare under asymmetric threats, and (2) the costs to construct and maintain the large combatants are very high and, as a result, the number of procured combatants will be decreased [9]. So, in this study, an ASW corvette is designed.

Corvettes have smaller displacement than frigates and destroyers. In the case of corvettes, one of the biggest problems is poor seakeeping because, in general, as displacement becomes smaller, the seakeeping becomes worse. One of the measures to overcome this problem is to use Small Waterplane Area Twin Hulls (SWATHs). However, SWATHs need more installed power compared to monohulls because of increased wetted surface area. The advantages of using TriSWACHs are the hullform's inherent good seakeeping at small displacement, good intact stability and large usable deck area compared to monohulls, and small installed power compared to SWATHs. These advantages are suited for corvette size vessels.

In addition, Small Waterplane Area (SWA) vessels has some acoustic advantages compared to monohulls: (1) the lower ship motions of the SWA vessels provide better flow into the propellers and decrease cavitation noise, (2) the lower ship motions decrease flow noise on the hull and sonar dome, and (3) SWA design offers the isolation of machinery noise. Therefore, this study explores the possibility of using a TriSWACH hullform as an ASW corvette.

1.3 Existing Corvettes

Several existing corvettes were reviewed to determine the requirements for the TriSWACH ASW corvette. Jane's Fighting Ships 2010-11 [5] was used for the comparison of the corvettes, and the definition of "corvette" was according to that category in the book. While ABUKUMA class was categorized as a "frigate", the vessel

was added to the study because it was an ASW frigate and the displacement was similar to the listed corvettes. Table 1 shows the comparison of the vessels. As seen in the table, full load displacement is about 1,000-2,500 mt, maximum speed is 24-30 knots, cruising speed is 15-20 knots, endurance range is 2,500-4,000 nm. As armaments, most vessels have SSMs, a 76 mm gun, torpedoes and sonar. Some vessels have SAMs and a flight deck. For these vessels, the sizes are not large enough to include a hanger for standard size helicopters. Except ABUKUMA, the vessels do not have SUMs. Figure 1 shows ABUKUMA class, and Figure 2 shows K130 class.

Table 1 – Corvette Size Vessels

Class	ABUKUMA	BADR	K130	SIGMA	MINERVA
Country	Japan	Saudi Arabia	Germany	Morocco	Italy
Commissioned	1989	1980	2008	2010	1987
Full Load Displacement (mt)	2,550	1,038	1,840	2,100	1,285
Max. Speed (knots)	27	30	26	28	24
Endurance Speed (knots)	Unknown	20	15	18	18
Endurance Range (nm)	Unknown	4,000	2,500	4,000	3,500
Manning	120	58	58	91	106
SSM	X	X	X	X	
SAM			X	X	X
SUM	X				
76mm Gun	X	X	X	X	X
Torpedo	X	X		X	X
Sonar	X	X		X	X
Flight Deck			X	X	
Hanger			X (for UAV)	Option	

Figure 1 – ABUKUMA Class [8]

Figure 2 – K130 Class [1]

2 Requirements and Standards

2.1 Requirements

Table 2 shows the requirements for the TriSWACH. The requirements were determined by referring to the above mentioned comparison. VLAs and a flight deck were included in the threshold requirements. To enhance the capability as an ASW corvette, Towed Array Sonar (TAS) and a hanger were added to the objective requirements.

Table 2 – Requirements Specification

	Threshold	**Objective**
Full Load Displacement	2,000 mt	1,000 mt
Maximum Speed	25 knots	30 knots
Endurance Speed	15 knots	20 knots
Endurance Range	3,500 nm	4,000 nm
Endurance	30 days	45 days
Armament	1 57mm gun, 1 RAM, 8 SSM, 6 torpedo tube, 8 VLA (1 VLS module) Hull mounted sonar	1 57mm gun, 1 RAM, 8 SSM, 6 torpedo tube, 8 VLA (1 VLS module) Hull mounted sonar TAS
Aviation Capability	Flight deck for 1 SH-60 class helo	Flight deck and hanger for 1 SH-60 class helo

2.2 Standards

Due to the combatant role of the vessel, it was designed using naval standards. The naval stability standards in use were DDS 079-1 for stability, and DDS 200-1 for endurance fuel. For the purpose of the concept design, only standards which affected the overall design were considered. When the detailed design process starts, all U.S. Navy standards will be applied to it.

3 Design

3.1 Design Process

Based on the above mentioned requirements, the design spiral was conducted. The only additional requirement was the use of a specified hullform. To provide breakdowns of each ship subsystem, the basic methods were to scale the weight and volume of existing vessels using appropriate parameters.

3.2 Design Characteristics

In Table 3, the principal dimensions and performance characteristics of the TriSWACH ASW corvette are presented as a comparison with TRITON. The hullform was a previously tested TriSWACH hullform which was a geosym scaled to fit the requirements. As seen in the table, the TriSWACH has a higher ratio of sidehulls' displacement to a centerhull's displacement than TRITON. The larger sidehulls were derived from intact stability analysis (Section 3.3.6). For damping, the TriSWACH has both forward-fins and aft-fins like SWATHs. The sizes of appendages were determined using existing SWATH's data.

Table 3 – Principal Dimensions and Performance Characteristics

	TriSWACH	TRITON [11]
Hullform	scaled from a previously tested TriSWACH model	Trimaran
Hull Material	Steel	Steel
Full Load Displacement	1,845 mt	1,100 mt
L_{WL}	102 m	91 m
B_{MAX}	24.3 m	22.5 m
Depth at Main Deck	10.5 m	9.0 m
T_{WL}	5.1 m	3.2 m
Sidehull to Centerhull L_{WL} ratio	34 %	38 %
Sidehull to Centerhull Displacement ratio	12 %	4 %
Sidehull Longitudinal Position	0.6%L_{WL} forward midship	2.5%L_{WL} aft midship
Maximum Speed	25 knots	20 knots
Endurance Range	3,500 nm at 15 knots	3,000 nm at 12 knots
Endurance Day	30 days	20 days
Total Installed Power	12,400 kW	4,400 kW
Propulsion System	Diesel Electric	Diesel Electric
Propulsor	1 contra-rotating propellers	1 conventional propeller
Auxiliary Propulsor	1 retractable thruster	2 right angle drive thruster
Appendage	rudder (4% of L_{WL}xT_{WL}) forward-fins (4% of A_W) aft-fins (7% of A_W)	rudder bilge keel
Manning	59	24

3.3 Hullform

3.3.1 TriSWACH

The design requirements specified the use of the previously tested TriSWACH hullform to exploit the availability of tank test data. In Figure 3, the hullform, which was developed by CISD and the ACCeSS team, is shown. In this figure, each number means station number. Figure 4 shows cross-sectional area curves of both a centerhull alone and one double displacement sidehull (section 3.3.6). Each area is non-dimensionalized using the maximum sectional area (A_{MAX}) of the centerhull. Prismatic coefficient of the centerhull is 0.746. This centerhull was developed using the SWAD program [13] which was developed in NAVSEA and utilizes thin ship theory to estimate residuary resistance. The design Froude number of this hullform was 0.556 [4].

The design of TriSWACHs is similar to conventional trimarans but with a centerhull which has small waterplane area. One centerhull and two sidehulls are located below a cross deck and connected to the cross deck. The small waterplane area of the centerhull and the sidehulls provide significant benefits in seakeeping. Compared with similar sized monohulls and conventional trimarans, the TriSWACHs can operate in higher sea states. The slenderness of both the centerhull and the sidehulls reduces wavemaking resistance which becomes a major factor at high speeds. Also, this hullform provides a high ratio of deck area to displacement.

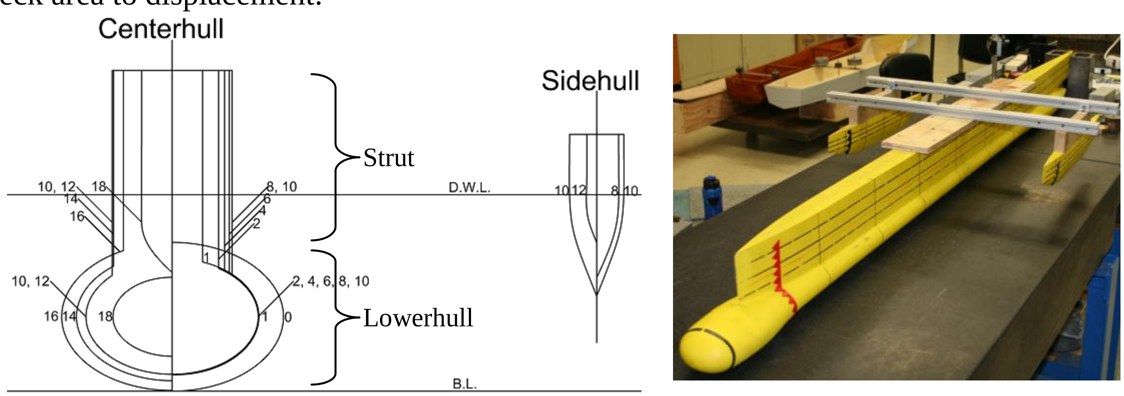


Figure 3 – TriSWACH Hullform (Left: Body Plan, Right: Model)

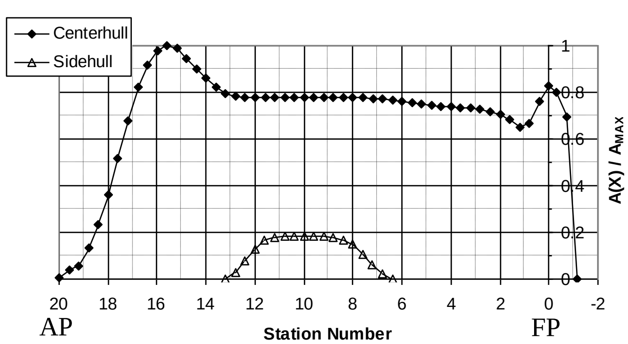


Figure 4 – Cross-Sectional Area Curve

3.3.2 Tank Test

To understand the impact of sidehull configurations on C_R, tank tests for eleven cases were conducted by the ACCeSS team (U.S. Naval Academy, Stevens Institute of Technology, and Webb Institute). Table 4 shows the test conditions for the eleven cases. For four cases of the eleven cases, Figure 5 shows sidehull positions of model scale.

Table 4 – Test Conditions

	Sidehull Longitudinal Position	Sidehull Transverse Position	Sidehull Displacement	U.S. Naval Academy	Stevens Institute of Technology	Webb Institute
1	Forward	Inboard	Original Displacement			X
2		Mid			X	X
3		Outboard				X
4	Mid	Inboard		X	X	X
5		Mid				X
6		Outboard			X	X
7	Aft	Inboard				X
8		Mid		X	X	X
9		Outboard				X
10	Mid	Inboard	Double Displacement	X		
11	Aft	Mid		X		

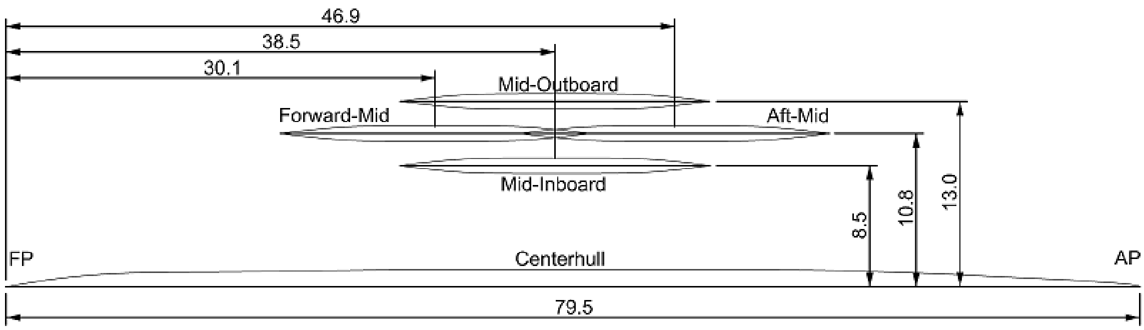


Figure 5 – Sidehull Positions (unit: inch)

3.3.3 AEGIR

AEGIR is a time-domain seakeeping code that uses an advanced, high-order, boundary element method (BEM) to solve the three dimensional potential flow. It also includes a fully non-linear steady-state solver for wavemaking resistance, sinkage and trim predictions. It interfaces with a popular CAD program, Rhinoceros, for hull geometry modeling and has an automated gridding feature that enables users with little CFD tool experience to create free surface and body geometry grids. In this design, AEGIR was used for parametric studies.

3.3.4 Centerhull Slenderness

To evaluate the impact of slenderness of the centerhull alone on P_E, a parametric study was conducted using AEGIR. As constraints, displacement (1,609 mt) and the beam-to-draft ratio (B_{WL}/T_{WL}) were constant. The evaluated speed was 25 knots. To estimate C_T, the following equation was used:

$$C_T = C_W + C_F + C_A \tag{1}$$

where C_W is from AEGIR results, C_F is from ITTC 1957 Friction Line, and $C_A = 0.0005$. Figure 6 shows the impact of the slenderness of the centerhull alone on P_E. Between 82 m and 112 m, as L_{WL} is increased, P_E is decreased. In this case, L_{WL} = 102 m seems appropriate because using a hull that is too slender is inefficient for arrangements and increases longitudinal bending moment (i.e. structural weight), while P_E is not reduced significantly.

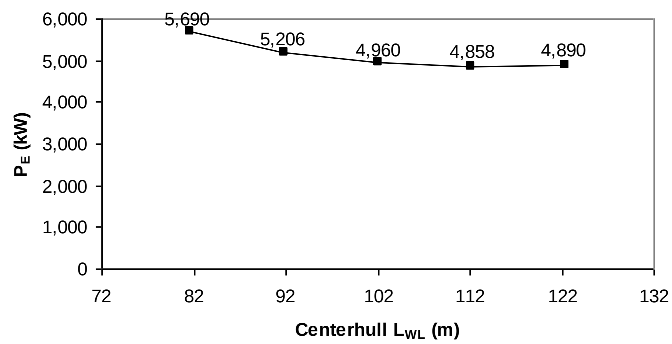


Figure 6 – Impact of Slenderness of Centerhull alone on P_E

3.3.5 Sidehull Configuration (Resistance and Powering)

To understand the impact of sidehull positions on resistance at maximum speed, C_R (= C_T - C_F) from tank tests, which were conducted at Webb Institute, and C_W from AEGIR results are shown in Figure 7. The evaluated Froude number was 0.407, which corresponds to 25 knots at full scale. As seen in the figure, the change of C_R with sidehull position is not simple, but AEGIR could predict trends in resistance well. This means that AEGIR has the capability to look for the best position by establishing appropriate constraints which are derived from a ship design point of view.

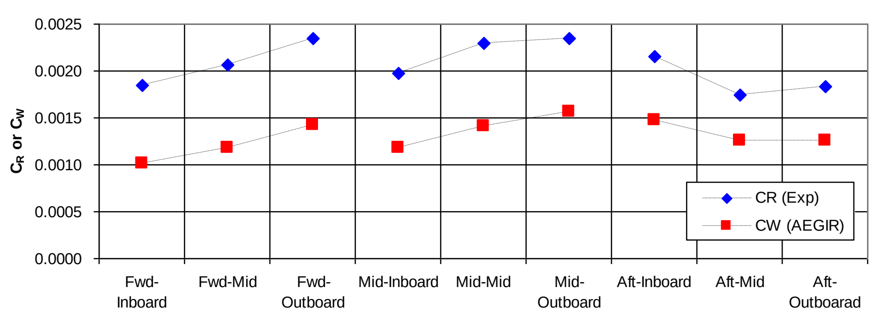


Figure 7 – Impact of Sidehull Positions on C_R and C_W at Maximum Speed

To evaluate the impact of sidehull positions on C_R and P_E, C_R (= C_T - C_F - C_{HAMA}) from tank tests, which were conducted at Stevens Institute of Technology, and P_E for four cases (Mid-Inboard, Mid-Outboard, Fwd-Mid and Aft-Mid) are shown in Figure 8. The evaluated displacement was 1,800 mt. Mid-Inboard was the best at the maximum speed, while Aft-Mid was the best at the endurance speed. In the case of the TriSWACH, minimizing the installed power is important because the volume in the lower hull to install motors is limited. However, to determine the appropriate position of the sidehulls, it is necessary to evaluate stability, volume, weight, general arrangement, initial trim, etc. After an iterative analysis of the data, Mid-Inboard was selected for the design.

One of the biggest reasons to select the longitudinal "Mid" position was to minimize initial trim. The longitudinal center of gravity is dependent on sidehull positions because main generator rooms, which house heave equipment, are located on the cross deck (Figure 15) while, the center of flotation is close to midship even if the sidehull positions are changed. In this case, it is necessary to locate sidehulls close to the midship to minimize the initial trim.

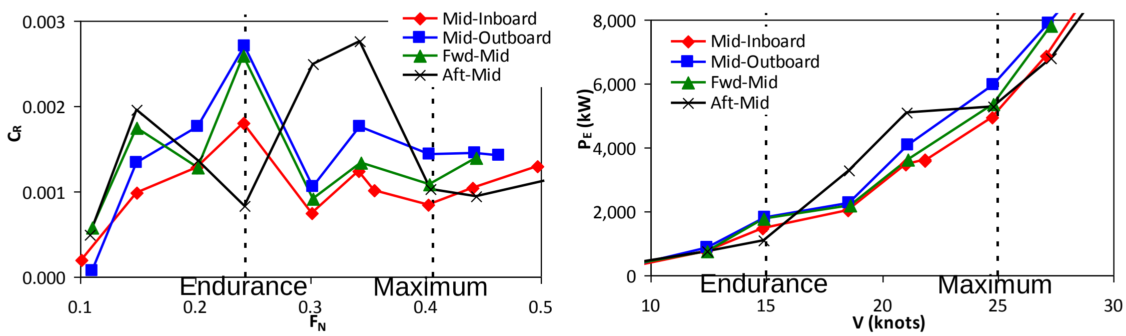


Figure 8 – Impact of Sidehull Positions on C_R and P_E

3.3.6 Sidehull Configuration (Stability)

To determine sidehull configurations, intact stability was evaluated. Free surface effect was not considered because the TriSWACH has a very slender centerhull, which includes tanks, and the free surface effect is not significant. The evaluated displacement was the full load condition only because the TriSWACH has enough volume for clean ballast tanks to compensate consumed fuel and the full load displacement is similar to minimum operating condition. In the case of Mid-Inboard with the original displacement sidehulls, GM was about 0.1 m. This number had to be increased by an appropriate measure. For trimaran hullforms, the following equation is used to calculate BM:

$$BM = \left(I_{Centerhull} + 2I_{Sidehull} + 2A_{Sidehull} \cdot b^2\right)/V \qquad (2)$$

where I = transverse moment of inertia of waterplane, A = waterplane area, b = span between centerhull's centerline and sidehull's centerline, V = volume of displacement of trimaran. The percentage of each term to BM was 3.4%, 0.2% and 96.4%. This means

that, in the case of the TriSWACH, BM and KM depend strongly on both the waterplane area of the sidehull and the span.

To increase GM, the following cases were considered: to increase (1) sidehull span, (2) sidehull length, (3) sidehull beam, and (4) both sidehull length and beam. However, according to the basic approach which utilizes the existing tank test data and to minimize the initial trim, there are three options: (1) Mid-Inboard with double displacement sidehulls, (2) Mid-Mid with original displacement sidehulls and (3) Mid-Outboard with original displacement sidehulls. Table 5 shows comparisons among the three cases. Only the impacts on KM, hull volume and hull structural weight were considered. As seen in the table, KM is improved for the three cases, while case (3) has an excess value for KM. In the same way as the previous section, to determine appropriate sidehull configurations, the other factors (powering, volume, weight, general arrangement, etc.) have to be evaluated. After an iterative analysis, Mid-Inboard with double displacement sidehulls was selected.

Table 5 – Impact of Sidehull Configurations on Intact Stability

Case	Sidehull Position	Sidehull Displacement	KM (m)	Hull Volume (m3)	Hull Structural Weight (mt)
	Mid-Inboard	Original	7.2	-	-
(1)	Mid-Inboard	Double	9.3	8,230	706
(2)	Mid-Mid	Original	9.7	8,386	717
(3)	Mid-Outboard	Original	12.9	9,358	790

Table 6 shows the comparison of GM-to-B_{WL} ratio (GM/B_{WL}) for several vessels. The Mid-Inboard configuration selected seems appropriate because GM/B_{WL} of the TriSWACH is among those of existing monohulls and multihulls.

Table 6 – Comparison of GM/B_{WL}

Class	TriSWACH	BADR	FFG 7	T-AGOS 19	LCS 2
Hullform	TriSWACH	Monohull	Monohull	SWATH	Trimaran
Full Load Displacement (mt)	1,800	929	3,670	3,375	3,011
GM/B_{WL} (%)	9	15	9	14	17

Figure 9 shows GZ curve of the Mid-Inboard with double displacement sidehulls compared to that of the Mid-Inboard with original displacement sidehulls. According to DDS 079-1, levers of “beam winds and rolling” and “high speed turn” (assuming the tactical diameter = 4.5 L_{WL}) are also shown in the figure. The criteria for intact stability were satisfied for the two cases.

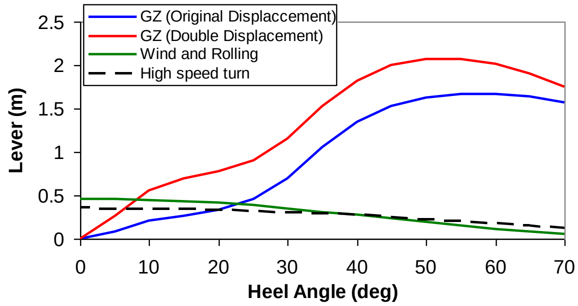


Figure 9 – GZ Curve

3.4 Mission Systems

By referring to several existing corvettes, the following mission systems were selected for the TriSWACH ASW corvette.

Armament: 1 - 57 mm gun, 1 - RAM, 8 - SSM, 6 - torpedo tube,
8 - VLA (1 - VLS module), SQS-56 hull mounted sonar,
CAPTAS Nano
C4ISR suite: Based on BADR class design
Aviation: SH-60 capable flight deck

As an ASW corvette, the TriSWACH has torpedo tubes, VLAs, hull mounted sonar, CAPTAS Nano and a helo flight deck. The flight deck for SH-60 class is also compatible with smaller vehicles (e.g. UAV).

3.5 Powering

A powering estimate for the TriSWACH was made using tank test data of the Mid-Inboard configuration with double displacement sidehulls which was tested at the U.S. Naval Academy. The evaluated displacement was 1,840 mt. Figure 10 shows a shaft power (P_S) curve of the TriSWACH compared to that of the BADR class hullform scaled to the same displacement. Except for Propulsive Coefficients (PC) (the TriSWACH has contra-rotating propellers (CRPs), while the BADR has two conventional propellers), the other conditions (displacement, C_A and resistance margin) were the same for both cases. At 25 knots, the TriSWACH required shaft power of 8,500 kW. At this speed, shaft power is reduced by 2,500 kW when compared to the BADR class hullform. The peak around 17 knots in the power curve corresponds to the hump in the curve of C_R of the TriSWACH.

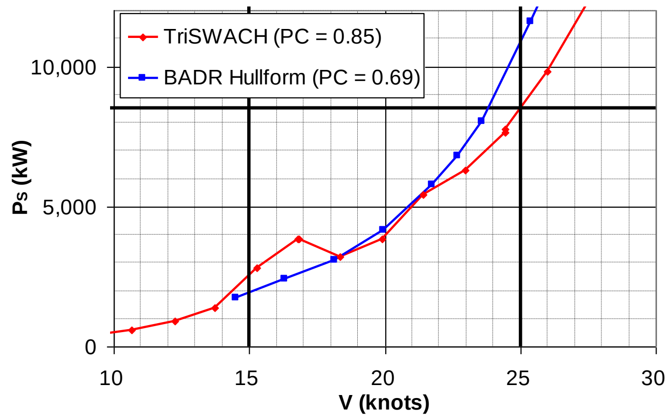


Figure 10 – Power Curve

To estimate C_T, effective power (P_E) and shaft power (P_S), the following equations were used:

$$C_T = C_R + C_F + C_A \tag{3}$$

$$P_E = \left\{ \frac{1}{2} \rho V^2 S C_T \cdot (1 + margin) \right\} \cdot V \tag{4}$$

$$P_S = \frac{P_E}{PC} \tag{5}$$

where:

C_R is from tank tests,
C_F is from ITTC 1957 Friction Line,
$C_A = 0.0005$.

As the influence of appendages (forward-fins, aft-fins and a rudder), only the increase of wetted surface area was considered. The margin on estimated resistance was 6% because of the existence of the tank test results. The PC of 0.85 was used to represent a selection of CRPs as a propulsor for the TriSWACH. The value was based on model test data for the CRPs on a SWATH design which can be found in NSWCCD report [6].

3.6 Propulsion and Electrical System

The very slender hull of the TriSWACH and the selected CRP system limited the ability to use a mechanical drive configuration. An integrated electric propulsion plant was selected, therefore, as major equipment, so that the main generators could be positioned in the less space constrainted spaces above the 2nd deck. Also, the ability to adjust intact stability by changing sidehull configurations facilitates adoption of the integrated electric propulsion plant option.

An electric load for ship services of 830 kW was estimated by analyzing the electric loads of several similarly sized vessels. The total installed power was determined as follows,

$$(8{,}500 \times 1.1 + 830 \times 1.2) \times 1.2 \approx 12{,}400 \text{ kW} \tag{6}$$

A transmission loss of 10 % was added to the shaft power to account for losses within the shafting, the electric motors, the variable speed drives and electrical distribution system. A service life growth margin of 20% was added to the ship service load, and an additional 20% margin was added to the total electrical load to ensure the selected power generation plant operated at around 80% of its maximum continuous rating (MCR).

Diesel electric power generation was selected because it has good specific fuel consumption (SFC) compared to gas turbine based options and because the required power was low enough to be within the power range of available diesels. Four MTU 20V 4000 (each about 3,100 kW) diesel generators were selected because:

(1) Four engines matched the arrangement, allowing an even split in power between two separated spaces, enhancing overall availability and redundancy.

(2) The 20V 4000 is currently the most powerful engine in its class allowing the use of lightweight and space efficient high speed diesels higher up in the vessel design.

Figure 11 shows the proposed power and propulsion configuration. Two propulsion motors based on the ABB permanent magnet (PM) design used within their range of compact Azipod electric pods (specifically the CO 1400 design) were assumed because of their small size to simplify installation in the very slender hull. To achieve 8,500 kW and drive CRPs, the motors should be in a tandem arrangement with each motor driving one propeller. It should be noted that some technical risk may need to be overcome in combining tandem electric motors with a CRP system; this will require some further analysis.

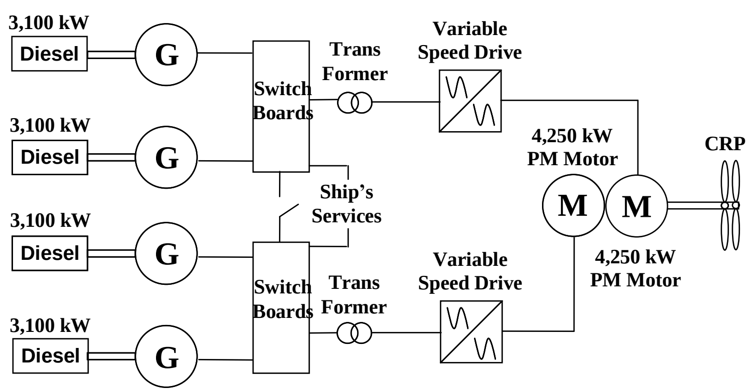


Figure 11 – Power and Propulsion Configuration

3.7 Manning

The manning of the TriSWACH was assumed to be 59. Table 7 shows the process of the estimation for the manning. To estimate the manning, Douangaphaivong's data [2] was

referred to. At first, as a baseline, the manning of BADR class was used. Secondly, the difference of the mission systems (VLAs and a flight deck) between the TriSWACH and the BADR was considered, and the manning of CG 47 for the mission systems was added. The original total manning became 71. Here, the difference of propulsion systems (integrated electric propulsion and mechanical drive propulsion) was not considered. Finally, to reduce the manning, the overall effects by the past U.S. Navy's reduced manning experiments were considered: "Smart Ship" program for CG 48 and "Optimal Manning Experiments" for DDG 69. As a result, the improved total manning estimate became 59. This number is realistic when referring to the manning of recent combatants (e.g. K130, which has similar displacement, is operated by 58 manning. LCS 2, which has larger displacement, is operated by 40 core crew.).

Table 7 – Manning

BADR class manning	58
MK41 Launcher Station	5
Helo Control Station	1
Flight Deck Control	6
JP5 Pump Room	1
Total (Original)	71
"Smart Ship" Effect	-4%
"Optimal Manning Experiment" Effect	-13%
Total (Improved)	59

3.8 Weight

Table 8 summarizes the estimated weights. Each of the weight groups is discussed individually. The KG was estimated using KG-to-Depth at the main deck ratio (KG/D) of existing vessels as a parameter for each weight category.

Table 8 – Weight Summary

SWBS	Weight (mt)
100 Hull Structures	709
200 Propulsion Plant	155
300 Electric Plant	187
400 Command and Surveillance	52
500 Auxiliary Systems	161
600 Outfit and Furnishings	102
700 Armament	47
Lightship Weight	1,413
Margin (10% Lightship Weight)	291
Loads	141
Full Load Displacement	1,845

3.8.1 Hull Structures

To estimate major hull structural weights (hull plating, hull framing, inner bottom plating, bulkhead and deck), TRITON's structural density was used because (1) both the TriSWACH and TRITON are trimarans and available trimaran data were limited, (2) the displacement was similar and (3) the hull material was the same. Here, the density indicates the ratio of structural weight to hull volume. The density of the TRITON was 0.073 mt/m^3 for the main hull (below the main deck) and 0.044 mt/m^3 for the superstructure (above the main deck). For the other structural weights, TRITON's weights and BADR's weights were scaled using several parameters (hull volume, shaft power, installed electric power, etc.).

3.8.2 Propulsion Plant and Electric Plant

The weights of diesel generators and motors were taken from specific manufacturer estimates. For a retractable thruster, FFG 7's weight was used. For the other weights, TRITON's weights were scaled using several parameters (hull volume, shaft power, installed electric power and shaft torque).

3.8.3 Command and Surveillance

This weight group was based on BADR's weight.

3.8.4 Auxiliary Systems, Outfit and Furnishings

Trendlines using data for several vessels (TRITON, T-AGOS 19, LCS 2, X-Craft and BADR) were made using hull volume as a scaling parameter, and the weights were estimated using the trendlines.

3.8.5 Armament

This weight group was estimated by summing up the weights of each of the weapon systems.

3.8.6 Loads

The required fuel weight was estimated according to DDS 200-1. The weights of ship ammunitions were estimated by summing up the weights of each of the weapon systems. The other weights were scaled using several parameters (manning, endurance day, etc.).

3.8.7 Margin

To determine the weight margin, NAVSEA "Policy for weight and vertical center of gravity above bottom of keel (KG) margins for surface ships" [10] was referred to. Weight margins depend on weight risks. A margin of 10% of the lightship weight was added because the weight risk of the TriSWACH was thought to be a "new concept design with some significant level of uncertainty", not "a high level of uncertainty".

3.8.8 Comparison

To understand the features of the TriSWACH, Table 9 shows the comparison of the percentages of the weights. The percentage of hull structural weight of the TriSWACH is larger than that of BADR because it is a multihull vessel. The sum of weights of hull structure, propulsion plant and electric plant becomes about three-fourths of the lightship weight. This means that the weight estimates of the three categories are more important for the TriSWACH than monohulls.

Table 9 – Weight Comparison

SWBS	Weight Percentage (%)		
	TriSWACH	BADR (Monohull)	TRITON (Trimaran)
Hull Material	Steel	Steel	Steel
100 Hull Structures	50	42	62
200 Propulsion Plant	11	17	7
300 Electric Plant	13	6	11
400 Command and Surveillance	4	7	0
500 Auxiliary Systems	11	17	9
600 Outfit and Furnishings	7	8	11
700 Armament	3	3	0
Lightship Weight	100	100	100

3.9 Ship Arrangements

3.9.1 Volume and Area

Area and volume requirements of the TriSWACH were scaled from several vessels using appropriate parameters. For main generator rooms and the control station for the diesel electric propulsion on the 2nd deck, a trendline of two diesel electric propulsion vessels (T-AGOS 23 and T-AKE) was used. For required volume in the centerhull, the volume of T-AGOS 23 was scaled using several parameters (hull volume, displacement, installed power and manning) because the arrangement of the TriSWACH in the centerhull is similar to that of SWATHs. For living spaces, the habitability standards of LCS 2 were

used to reflect the habitability of a recent frigate size trimaran. For the other spaces, the area and volume of BADR were scaled using several parameters (hull volume, displacement and installed power). For area and volume requirements, space was allocated to each compartment. Table 10 shows the required volume, and Appendix shows the summary of the required volume. Table 11 shows available volume. The available volume was nearly equal to the required volume. About 40% of the available volume was achieved below the 2nd deck. The volume in the sidehulls was not included because of the requirement from damage stability (section 3.10).

Table 10 – Required Volume

SSCS	Required Volume (m^3)
1 Military Mission	933
2 Human Support	845
3 Ship Support	2,447
4 Ship Machinery	2,841
Total	7,066

Table 11 – Available Volume

Location	Available Volume	
	(m^3)	(%)
Below 2nd Deck	2,976	42
2nd Deck	2,977	42
Main Deck	869	12
01 Level	320	4
Total	7,142	100

Table 12 shows the comparison of the volume between the TriSWACH and BADR. Although installed power for propulsion of the TriSWACH is smaller than that of the BADR, the machinery volume percentage of the TriSWACH is larger than that of the BADR because the TriSWACH is using diesel electric propulsion instead of a mechanical drive propulsion.

Table 12 – Volume Comparison

	TriSWACH	BADR (Monohull)
Propulsion System	Diesel Electric	CODOG
Installed Power for Propulsion	12,400 kW	19,750 kW
SSCS	Volume Percentage (%)	
1 Military Mission	13	18
2 Human Support	12	21
3 Ship Support	35	26
4 Ship Machinery	40	35
Total	100	100

3.9.2 General Arrangement

Figure 12 shows the midship section. The clearance between the design waterline and the wet deck was determined from existing SWATH vessel data using L_{WL} of sidehulls as a parameter. All deck heights were 2.5 m which was determined by referring to the BADR's General Arrangements (GA). For stability over a range of heel angles, flares above the design waterline were added to the insides of the sidehulls. For RCS reduction, flares of 20 degree were added to the main hull and the superstructure.

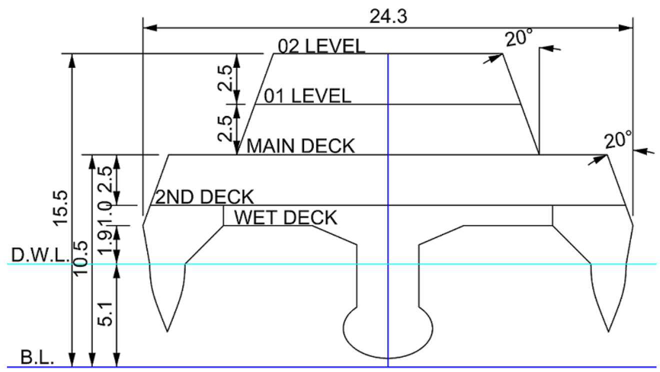
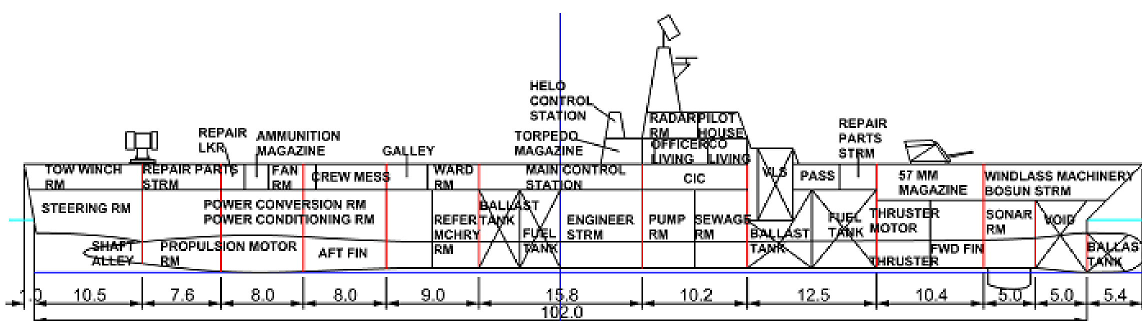


Figure 12 – Midship Section

Figure 13 shows the inboard profile. In this figure, red lines indicate the positions of watertight bulkheads. The 57 mm gun and hull mounted sonar are located in the fore-part, and the RAM is located in the aft-part. The motor room, power conversion room and power conditioning room are located in the aft-part of the centerhull. The total volume of fuel tanks is nearly equal to that of clean ballast tanks. A retractable thruster is located in the fore-part of the centerhull because the TriSWACH is a single shaft vessel and needs an additional propulsor for redundancy.



Midship

Figure 13 – Inboard Profile

Figure 14 shows the GA of the fore-part on the 2nd deck. In this part, there are the magazine for the 57 mm gun and VLS equipment room.

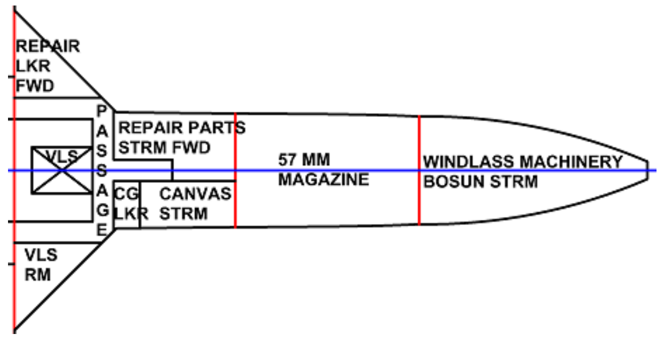


Figure 14 – Fore-Part on 2nd Deck

Figure 15 shows the GA of the mid-part on the 2nd deck. This part is the most valuable space for the TriSWACH. For protection of vital spaces, mission systems and the main control station are located near the centerline. For localization of vital area and easy access, mission systems are located in the fore-part which is just under the superstructure. The main generator rooms and main control room, which house heavy equipment, are located near midship to minimize the initial trim of the vessel. By locating the generators and control systems for propulsion in this part, it is possible to utilize the space in the strut of the centerhull and the space in the sidehulls. By separating the main generator rooms into right and left sides, separation and redundancy for the propulsion systems are increased. The communal space (crew mess, galley and wardroom) are located in the aft-part.

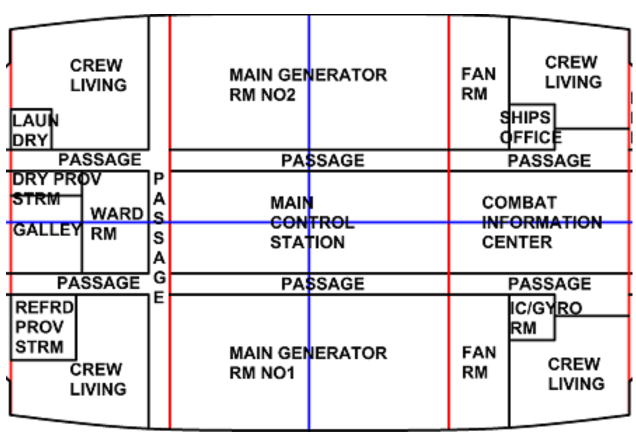


Figure 15 – Mid-Part on 2nd Deck

Figure 16 shows the GA of the aft-part on the 2nd deck. For TAS, the tow winch room is located in the most aft part.

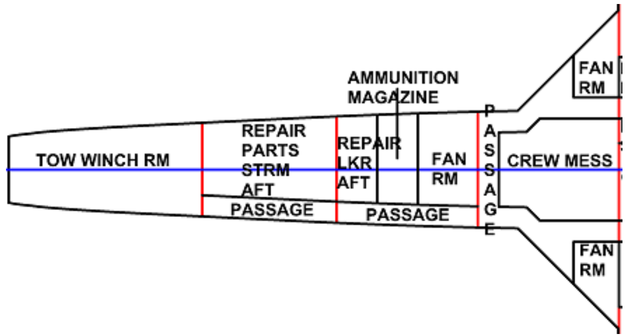


Figure 16 – Aft-Part on 2nd Deck

Figure 17 shows the GA of the mid-part on the main deck. Torpedo tubes and SSM are located in the aft-part. The location of the flight deck makes helicopter operations easier because it is close to midship and the vertical velocity is reduced. To support ASW helicopter operations, the torpedo magazine and sonobuoy storeroom are located near the flight deck.

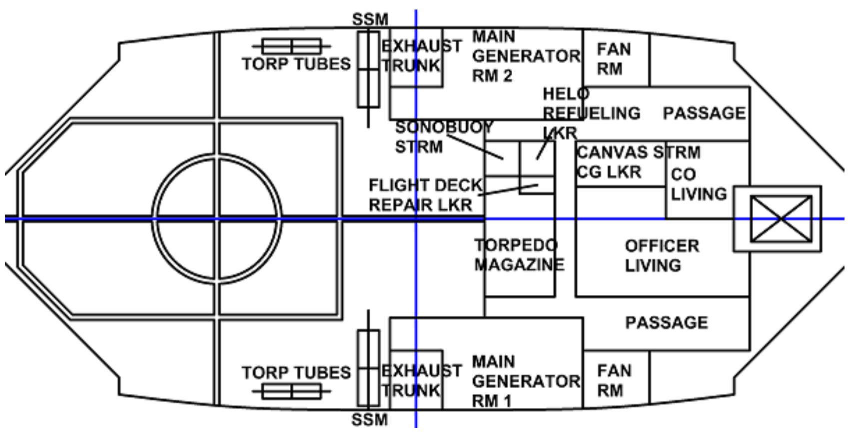


Figure 17 – Mid-Part on Main Deck

Figure 18 shows the GA of the 01 level where the pilot house, radar room and exterior communication center are located. For localization of vital area, the radar room and exterior communication center are located under the 02 level, where there are radars and antennas. For helicopter operations, the helicopter control station is located on this deck.

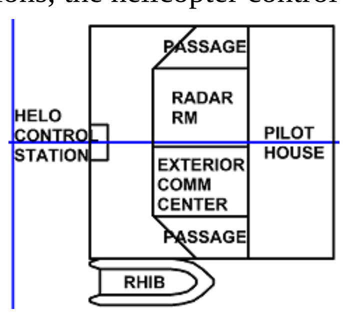


Figure 18 – 01 Level

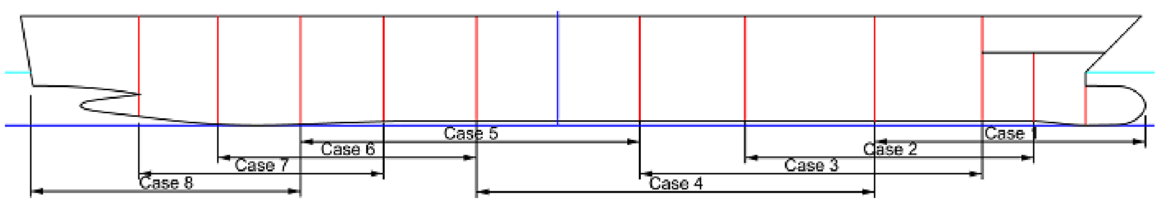
3.10 Damaged Stability

For damaged stability, DDS 079-1 was used. The only evaluated condition was the full load displacement because for the same reason as intact stability (section 3.3.6). The longitudinal extent of the damage was 15% L_{WL} (i.e. 15.3 m).

For symmetrical damage cases, Table 13 shows the clearance between waterlines after damage and a margin line, which is located at 76 mm below the main deck. The permeability of all compartments was assumed to be 0.8, and both the centerhull and two sidehulls were damaged at the same time. As seen in the table, the cases when the fore-part is damaged are severe as the trim is large because of the small M_{cm} (moment to change trim one cm) of the TriSWACH.

Table 13 – Clearance between Waterline after Damage and Margin Line

Damage Case	1	2	3	4	5	6	7	8
Mean Draft (m)	5.7	6.0	6.4	7.1	6.9	6.2	6.0	5.9
Trim (degree)	-4.8	-4.8	-3.3	-1.1	0.9	2.2	2.7	3.1
Clearance (m)	0.4	0.1	1.1	2.4	2.7	2.3	2.0	1.7



As an asymmetrical damage case, Figure 19 shows the most severe case which occurs when one sidehull is damaged and both the other sidehull and the centerhull are intact. In this case, the permeability of each compartment was determined by the GA. In the figure, there are two curves: (1) the permeability in the sidehull = 0.95, which corresponds to stores, and (2) 0.50, which corresponds to foam filled spaces. In the case of 0.95, the vessel will capsize. By filling the spaces with the foam, the criteria are satisfied. This solution is suggested by Dubrovsky [3]. The other way to improve this situation is to use longer sidehulls because it is possible to avoid the situation when all buoyancy in one sidehull is lost at one time. However, using longer sidehulls means an increase of the structural weight. As a result, the compartments in the sidehulls were assumed to be foam filled spaces. In this case, it is necessary to use fire resistance foam.

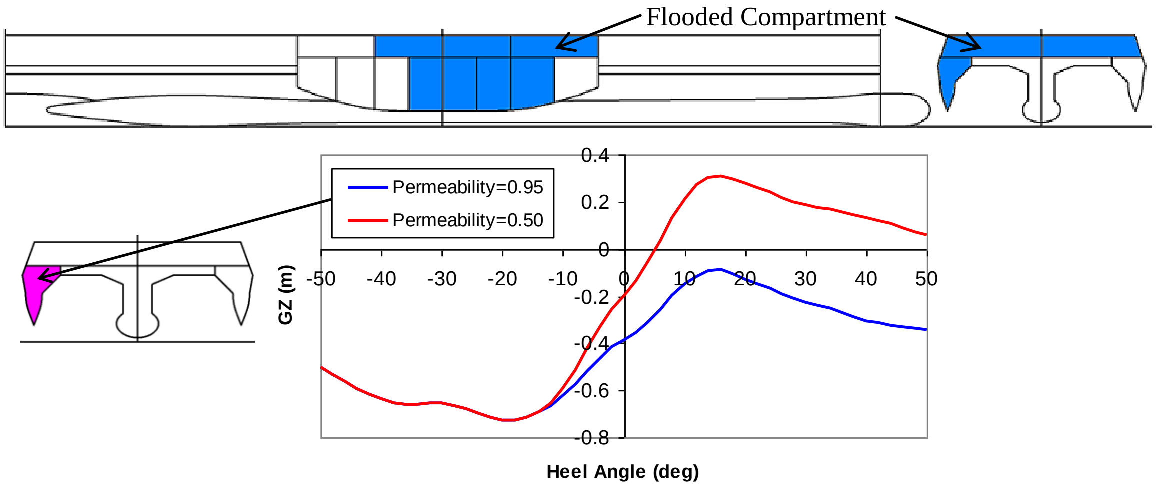


Figure 19 – GZ Curve for Most Severe Case

3.11 Titanium Hull

As seen in the previous section 3.8.8, the hull structures are about one-half of the lightship weight. This means that, if any lightweight materials are used for the hull structures, the weight will be decreased significantly. In this study, titanium was used as the lightweight material. The reasons why it was used rather than aluminum were for the advantages of the high specific strength, high corrosion resistance and high fire resistance. For the TriSWACH, Poole [12] studied the effects of the weight reduction by changing materials and frame spacing. According to this study, by using titanium instead of steel, it is possible to save 40 % of the major structural weight (hull plating, hull framing, inner bottom plating, bulkhead and deck). Table 14 shows the weight summary for the titanium hull structures compared to the steel ones. For both cases, all requirements for the ASW corvette have been satisfied. By using titanium, the weight reduction of the hull structures was 267 mt and that of the full load displacement was 314 mt.

Table 14 – Effect of Titanium Hull Structure

SWBS	Weight (mt)		
	Steel	Titanium	Difference
100 Hull Structures	709	442	-267
200 Propulsion Plant	155	149	-6
300 Electric Plant	187	182	-5
400 Command and Surveillance	52	52	0
500 Auxiliary Systems	161	158	-3
600 Outfit and Furnishings	102	100	-2
700 Armament	47	47	0
Lightship Weight	1,413	1,130	-283
Loads	291	288	-3
Margin (10% Lightship Weight)	141	113	-28
Full Load Displacement	1,845	1,531	-314

4 Risks

4.1 Hull Structure

To estimate the major steel hull structural weights, TRITON's structural density was used. However, more detailed estimates are needed because the TriSWACH has the new concept hullform and the weight is about one-half of the lightship weight.

4.2 Propulsion

As the propulsor, the contra-rotating propellers (CRPs) were used, and the PC of 0.85 was assumed based on CRP model tests on SWATH hulls [6]. For more refined powering, the CRPs should be designed for the TriSWACH. Also, some technical risk may need to be overcome in combining tandem electric motors with a CRP system; this will require some further analysis.

4.3 Lowerhull Arrangement

In this design, a comparison between required volume and available volume for the lowerhull and strut was conducted. For the TriSWACH, arrangement of these spaces is more severe than monohulls and conventional trimarans because of the very slender hullform of the lower hull and strut. More detailed arrangement of these spaces is required to verify integration of equipment and hull structure while providing adequate access.

5 Conclusions

The objective of this project was to develop the concept design of the TriSWACH ASW corvette. This concept succeeded by completing the first iteration in the ship design spiral while meeting the initial design requirements.

The previously tested TriSWACH used for the design had a very slender centerhull and conventional sidehulls. At the maximum speed, the TriSWACH had good performance compared to the BADR class hullform. However, the performance at the cruising speed should be improved. The TriSWACH corvette had a maximum speed of 25 knots and could travel 3,500 nm at 15 knots.

At the full load displacement of 1,845 mt, the TriSWACH corvette has good seakeeping compared to similar sized monohulls and conventional trimarans. By utilizing the good seakeeping and the large deck area, helicopter operations on the flight deck should be improved.

The damaged stability for the TriSWACH was more severe than for conventional trimarans. This means that more attention has to be paid to design their sidehull configurations and compartments.

By using titanium, instead of steel, for the hull structure material, there is the possibility to reduce the weight by 314 mt at the full load displacement.

A number of high risk areas have been identified. In particular, both structural and propulsion analyses are more important for the TriSWACH than for the monohulls and conventional trimarans.

Although further analysis and design are required, the requirements for the TriSWACH ASW corvette have been fulfilled in a feasible manner by this concept design.

6 Future Works

This project was intended to generate an initial design concept. Therefore, the next stage of the process is a more detailed design which can build on the current work. In addition to the detailed design, a number of areas have been identified as requiring further attention:

Sidehull configurations - There are many combinations for sidehull configurations for the TriSWACH. Alternatives should be investigated to look for the optimal configuration.

Stability calculations - Detailed calculations have not been performed to assess the stability.

Seakeeping (tank tests and calculations) - One of the biggest advantages for the TriSWACH is good seakeeping. However, tank tests have not been conducted yet. For designers, it is difficult to select this hullform as there is no quantitative evaluation for seakeeping. The other way to evaluate the performance is to utilize analytical tools. In this case, the tools have to consider the damping effects of hullforms and fins (forward and aft) appropriately.

Risk Analysis - The items in section 4 “Risk” require further investigation to determine the risk level and identify possible steps that should be taken to minimize that risk.

7 References

1. Blohm + Voss Naval Home page, November 2011 <http://www.blohmvoss-naval.com/en/corvette-class-130.html>
2. Douangaphaivong, T. “Littoral Combat Ship (LCS) Manpower Requirements Analysis”, Naval Postgraduate School, December 2004

3. Dubrovsky, V., K. Matveev and S. Sutulo, "Small Waterplane Area Ships", Backbone Publishing Company, 2007
4. Hydromechanics Laboratory U.S. Naval Academy Final Report, "ONR HSSL A-PHASE 2 Towing Tank Tests of 4' SWATH Model", June 2006
5. Jane's Fighting Ships 2010-2011, IHS Global Ltd, 2010
6. Jenkins, D. S. and A. M. Reed. "Wake and Powering Predictions for SWATH 10, a 10,660 LT SWATH Ship, represented by Hull Models 5410 and 5410-1 and Contra-rotating Propellers 4872 & 4873 and 4878 & 4879", David W. Taylor Naval Ship Research and Development Center – Ship Performance Department Report, June 1986
7. Lewandowski, E. M., "The Effects of Aspect Ratio, Section Shape, and Reynolds Number on the Lift and Drag of a Series of Model Control Surfaces; Final Report", June 1994
8. Ministry of Defense, Japan Home page, November 2011 <http://www.mod.go.jp/msdf/formal/gallery/ships/dd/abukuma/229.html>
9. Mommsen, K., "Corvettes and Offshore Vessels", European Security and Defence, February 2009
10. NAVSEA INSTRUCTION 9096.6B "Policy for weight and vertical center of gravity above bottom of keel (KG) margins for surface ships", August 2001
11. Pattison, N. "The design and construction of RV Triton - the trimaran demonstrator", International Maritime Technology, vol. 113, 2001
12. Poole, A. "TriSWACH Material Trade-Off Analysis", Center for Innovation in Ship Design Technical Report, No. NSWCCD-CISD-2011/011, August 2011
13. Bauman, W., C. Kennell and G. Keramidas, "USER MANUAL FOR COMPUTER PROGRAM SWAD88", NAVSEA Technical Note No. 051-501-TN-0072, December 1988

Appendix – Required Volume Summary

Ship Space Classification System		Required Volume (m3)	Percentage
1.1	Command, Communications and Surveillance	449	6.4%
1.2	Weapons	217	3.1%
1.3	Aviation	90	1.3%
1.4	Amphibious	177	2.5%
1	Military Mission	933	13.2%
2.1	Living	577	8.2%
2.2	Commissary	255	3.6%
2.4	General Services	13	0.2%
2	Human Support	845	12.0%
3.1	Ship Control	173	2.4%
3.2	Damage Control	80	1.1%
3.3	Administration	18	0.3%
3.5	Deck Systems	30	0.4%
3.7	Stowage	723	10.2%
3.8	Access	894	12.7%
3.9	Tanks	529	7.5%
3	Ship Support	2,447	34.6%
4.1	Propulsion Systems	1,188	16.8%
4.2	Propulsor and Transmission Systems	10	0.1%
4.3	Auxiliary Systems	1,643	23.2%
4	Ship Machinery	2,841	40.2%
	Total	7,066	100.0%